AL-TR-1993-0008

AD-A262 616

# LOW-COST HELMET-MOUNTED DISPLAYS

Roger W. Leinenwever
Leonard G. Best
Bryce J. Ericksen

GE Government Services, Incorporated
General Electric Company
P.O. Box 137
Gilbert, AZ 85234

A R M S T R O N G L A B O R A T O R Y

HUMAN RESOURCES DIRECTORATE
AIRCREW TRAINING RESEARCH DIVISION
558 First Street
Williams Air Force Base, AZ 85240-6457



February 1993

Final Technical Report for Period April 1991 - April 1992

Approved for public release; distribution is unlimited.



AIR FORCE MATERIEL COMMAND
BROOKS AIR FORCE BASE, TEXAS

# NOTICES

This technical report is published as received and has not been edited by the technical editing staff of the Armstrong Laboratory.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by impli ...on, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Daniel H. Mudd

DANIEL H. MUDD
Contract Monitor

Dee H. Andrews

DEE H. ANDREWS, Technical Director
Aircrew Training Research Division

Lynn A. Carroll

LYNN A. CARROLL, Colonel, USAF
Chief, Aircrew Training Research Division

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | February 1993 | Final – April 1991 – April 1992 |

**4. TITLE AND SUBTITLE**
Low-Cost Helmet-Mounted Displays

**5. FUNDING NUMBERS**
C – F33615-88-C-0014
PE – 62205F
PR – 1123
TA – 04
WU – 01

**6. AUTHOR(S)**
Roger W. Leinenwever
Leonard G. Best
Bryce J. Ericksen

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
GE Government Services, Incorporated
General Electric Company
P.O. Box 137
Gilbert, AZ 85234

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)**
Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Division
558 First Street
Williams Air Force Base, AZ 85240-6457

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
AL-TR-1993-0008

**11. SUPPLEMENTARY NOTES**

Armstrong Laboratory Technical Monitor: Dan Mudd, (602) 983-6561

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** (Maximum 200 words)

This report contains two papers presented at the Helmet-Mounted Displays IV, International Symposium and Exhibition on Optical Engineering and Photonics, held at Orlando, FL on 20-24 April 1992. This symposium was sponsored by the Society of Photo-Optical Instrumentation Engineers (SPIE). The papers describe the development and demonstration of two helmet-mounted displays: a low-cost monochrome helmet display and a low-cost color helmet display, both with see-through optics. The present monochrome CRT display helmet design, through demonstrations and system measurements, provided positive data as a research device. The color LCD helmet display system was successfully completed and although the resolution of the LCD matrix structure is not suited for the application of small text in the presentation, the high contrast and vivid colors produced by the LCD, as well as the see-through function of the optics, provide the capability for a full field-of-regard visual simulation system which can be used in conjunction with low-cost cockpit training devices.

**14. SUBJECT TERMS**

| | | |
|---|---|---|
| Color | Flight training | Monochrome |
| CRT | Helmet-mounted displays | Optics |
| Displays | HMD | Simulators |
| | LCD | Visual displays |

**15. NUMBER OF PAGES**
18

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

## PREFACE

This report includes two papers which were presented at the Helmet-Mounted Display IV International Symposium and Exhibition on Optical Engineering and Photonics, at Orlando, FL, on 20-24 April 1992, which was sponsored by the Society of Photo-Optical Instrumentation Engineers (SPIE). The papers present the results of research performed by GE Government Services (GEGS) under contract to the Armstrong Laboratory, Aircrew Training Research Division (AL/HRA) at Williams Air Force Base, AZ in which two helmet-mounted display (HMD) systems were designed, manufactured, assembled, and demonstrated at AL/HRA. One helmet display utilized cathode ray tube technology and the other, liquid crystal display technology.

The work was conducted under the terms of Contract F33615-88-C-0014 with GEGS under AL/HRA Work Unit 1123-04-01, Technical Support for Visual and Sensor Scene Generators and Display Operations and Maintenance. The Laboratory Contract Monitor was Mr Daniel H. Mudd

Low-cost monochrome CRT helmet display

Roger W. Leinenwever

GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

Leonard G. Best

GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

Bryce J. Ericksen

Consultant to GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

## ABSTRACT

The goal of the cathode ray tube (CRT) helmet–mounted display (HMD) project was development and demonstration of a low cost monochrome display incorporating see-through optics. The HMD was also to be integrable with a variety of image generation systems and suitable for use with low-cost cockpit trainers and night vision goggle (NVG) training applications. A final goal for the HMD was to provide a full field of regard (FOR) using a head-tracker system. The resultant HMD design included two 1 inch CRTs used with a simple optical design of beam splitters and spherical mirrors. The design provides for approximately 50% transmission and reflectance capabilities for observing the 30° vertical x 40° horizontal biocular instantaneous field-of-view visual image from a graphic image generator system. This design provides for a theoretical maximum of 10.8% of the CRT image source intensity arriving at the eye. Initial tests of image intensity at the eye for an average out-the-window scene have yielded 12 to 13 Foot Lamberts with the capability of providing approximately 130 Foot Lamberts. Invoking a software "own ship" mask to "blackout" the visual image, the user can monitor "in-cockpit" instrumentation utilizing the see-through characteristics of the optics. The CRTs are operated at a TV line rate with a modulation transfer function (MTF) of approximately 65%. The small beam spot size and the high MTF provide for an enhanced image display. The display electronics are designed to provide a monochrome video picture based on an RS170 video input.

## 1. BACKGROUND

Over the past several decades tremendous strides have been made in computer image generation (CIG) for use with Department of Defense simulation devices. At the forefront of this simulation is the need to provide aircrew personnel the maximum amount of out-the-window (OTW) visual information for flying various types of mission-related tasks. With the increase in technology in image generation came the need to display the images everywhere the aircrew member needed to look. Coincidentally, fighter aircraft designs were changing to provide crews even greater visibility from the cockpit. The greater visibility, in turn, drove up the requirement for larger CIGs with greater capability and flexibility to support larger display systems. What started out as a one-window CRT visual display has blossomed into decahedron based infinity optic CRT displays and full field-of-view (FFOV) projection display dome systems. The lengthy assembly and intricate alignment of these large systems allows them to display high fidelity images, but the systems are generally considered permanent or long-term installations and lack mobility. These large systems might be utilized at a wing or base level by active duty aircrews, but squadron or unit level task training by all branches of service is the most common and effective. Thus, training in a particular task that might be accomplished on a low cost part task trainer (PTT) that requires a visual display is not presently available due to cost/training trade off and the lack of mobility of visual display systems. Low-cost trainer and visual systems usable and deployable at the squadron or unit are needed to support this level of task training. This situation is the driving force for research in low-cost display devices that will meet the requirements of Air Force mission task training.

## 2. INTRODUCTION

Research by the USAF Armstrong Laboratory, Aircrew Training Research Division (formerly The Air Force Human Resources Laboratory, Operations Training Division) in low-cost display systems is an important step in providing deployable squadron level integrated training devices. One type of display system being investigated is the helmet mounted display. Two HMD systems were designed, manufactured, assembled and demonstrated for Armstrong Laboratory under contract F33615–88–C–0014 with GE Government Services at Williams AFB, Arizona. These prototype developmental helmets are referred to as Phase I and Phase II helmets. The Phase I helmet utilizes CRT technology and is the subject of this paper.

## 3. SYSTEM DESIGN

### 3.1 General

The goal for the CRT HMD project was development and demonstration of a low-cost monochrome display incorporating see-through optics. The HMD was also to be integrable with a variety of image generation systems and suitable for use with low-cost part-task cockpit trainers and NVG training applications. A final goal for the HMD was to provide a full field-of-regard, utilizing a magnetic head-tracker system.

### 3.2 Optics

The optics of the CRT helmet were designed in coordination with Martin Shenker Optical Design Inc. as a non-exit pupil forming system with see through capability. Glass components were selected for the beam splitter prisms in the prototype system. A spherical mirror attached at four corners of the beam splitter is used to provide magnification of the optics to represent a 30° V x 40° H FOV design. Part of the optical design is based on the shape of the helmet and the attachment method to the helmet. Consideration of eye/head relief, interpupillary distance and 5 through 95 percentile values of eye position in USAF pilots[1] were driving factors in adjustment mechanism designs for the CRT/optics system.

### 3.3 Imaging system

The initial design consideration for applied video was to maintain RS170 capabilities at a minimum with the probability of increased line and pixel formats to be used later. The increased video format would minimize inherent artifacts caused by the selected FOV and interlacing function of the RS170 format. The maximum perceived resolution of 30° V x 40° H FOV at RS170 format is 3.7 arc minutes per pixel vertical and 3.75 arc minutes per pixel horizontal. If a RS343A standard type of format is utilized, the corresponding values become 1.8 arc minutes vertically and 2.34 arc minutes horizontally. Utilization of a 1" CRT with a small spot size, high brightness output and electronic drive system capable of multiple line rate input was selected as the imaging device that could meet the requirements.

### 3.4 Helmet

The CRT and optics are attached to a standard Air Force pilot helmet. The normal helmet liner is replaced with a dual air bladder system and sizing blocks to stabilize the helmet on the wearer's head. The air bladder system is provided as a quick method to fit the helmet to different personnel with various size heads. The helmet also has an earphone and microphone system so cockpit-to-cockpit or cockpit-to-simulator console communication can be used. A chin strap is utilized to help stabilize the helmet on the wearer's head so the head tracker electromagnetic receiver on the helmet does not change in position with respect to the wearer's eye point.

### 3.5 Head tracker

The head-tracking capability of the helmet utilizes a Polhemus 3 Space Tracker electromagnetic sensor system. Yaw, pitch and roll data are sensed via the tracker on command from a microprocessor and the resulting data is incorporated into control information. This information is utilized by a visual display generator representing spacial head position data with respect to the cockpit and simulated earth coordinate systems.

### 3.6 Weight and balance

The physical placement of the CRTs and optics on the forward part of the helmet require a small counterbalance on the back of the helmet in conjunction with the weight of the CRT cables which also act as a part of the counterbalance. Overall weight of the helmet was of major consideration due to neck strain, headaches and rotational inertia created from quick movements of the head. Strength and weight of proposed materials for the helmet, optics and attachment hardware were evaluated for use within delivery and cost constraints. Total weight of the helmet with bladder, sizing blocks, audio system, CRT/optics, head tracker receiver, cables and counter weight is approximately 6 1/4 pounds.

## 4. TECHNICAL DESIGN

### 4.1 Optics

The optic elements of the CRT helmet are designed as a non-exit pupil forming see-through system and allow for volume viewing. This arrangement does not require the wearer of the helmet to be at a critical location with respect to the optics to be able to see the entire scene being presented on the optics. The beam splitting function of the glass prisms allow the wearer to see through the prisms and transmissive spherical mirror for reading cockpit instrumentation when the "black" ownship cockpit mask function is in view. Viewing outside the ownship cockpit reveals the out-the-window scene. The present prisms are made from glass type BK7. The prisms are cut to vertically fold the light path forward to an angle of incidence of 40 degrees. This is done to accommodate the 10 degree forward tilt angle of mount of the CRTs to the helmet optics for access to adjustments. The optic design allows for 100% overlap biocular view of two 30° V x 40° H instantaneous fields of view through the two small beam splitter and spherical mirror systems. The spherical mirror has a magnification factor of approximately 9 times the image on the CRT fiber optic face plate. The beam splitters and mirrors for both optical paths are coated for approximately 50% transmission/reflectance. This design provides for a maximum of 10.8% of the CRT image source intensity to the eye. Initial tests of average image intensity at the eye for a normal daylight out-the-window scene has been measured at 12 to 13 Foot-Lamberts. This value can be varied depending on the brightness and contrast settings to match personal preference, however the capability of providing approximately 130 Foot-Lamberts is available if required. In a night vision goggle scene, the average brightness and contrast would be adjusted differently, but should be adjusted to accurately simulate a realistic scene.

### 4.2 Image display system

The image display system consists of two Thomas Electronics helmet mounted CRTs and the display electronics required to interface between the image source and to drive the CRTs. The CRTs selected met the requirements for size, weight, brightness, beam spot size, face plate type, plate thickness, cost and availability. The display electronics were manufactured by XYtron Limited based on design requirements established by the use of the selected CRT and image source being utilized for this project.

#### 4.2.1 CRT Display

The CRTs are monochrome, 1 inch, electromagnetically deflected raster tubes with a fiber optic face plate. They are designed to be utilized in aircraft helmet-mounted display systems. The CRTs are rated as 875 line capable with a 42% MTF, however at 525 line rates, the MTF is approximately 65%. The measured spot size of both CRTs is 6 ten-thousandths of an inch which is 25% better than the guaranteed size of 8 ten-thousandths of an inch. The small beam spot size and the high MTF provide for a very sharp image display.

##### 4.2.1.1 Fiber optic face plate

The fiber optic face plate of the Thomas tube has been ground and polished to match the curvature of the helmet optics to display an undistorted picture. After grinding, the standard fiber optic face plate still maintains its minimum thickness for safety integrity on ground training devices.

##### 4.2.1.2 Video format

The raster functions as well as the applied video are displayed in a 3x4 relationship over a 19 millimeter format representing an instantaneous 30° V x 40° H FOV. The brightness, contrast and focus of the picture are controlled remotely by low voltage potentiometers that may be adjusted by the HMD user. Typical brightness and contrast available to the eye point are 12.8 foot lamberts for average scene intensity with a 27.6:1 contrast ratio.

##### 4.2.1.3 CRT weight

The weight of a CRT with 12 inches of wires and connector is approximately 170 grams, however, with this application the wires (cable) are 7 feet long to reach the electronic source and provide complete user freedom in a cockpit. The cable(s) provide counter balance effect to the forward CRT placement through the securing of the cables to the back of the helmet by use of Velcro strips.

#### 4.2.2 Display Electronics

The display electronics were designed to automatically synchronize to composite monochrome video signals between 15 KHZ and 64 KHZ horizontal sweep frequency. The initial video format provided to the electronics was a 15.75 KHZ horizontal frequency

(RS170) monochrome video signal from a graphics work station. The display electronics system has the capability to drive the required signals over a 7–foot cable terminated at the CRT. The deflection signals are corrected for the effects of pincushion, barrel distortion, linearity distortion and curvature. The contrast, brightness and electronic focus controls are mounted on a small remote hand-held assembly so the user of the helmet display system may tune the picture for best personal performance. The hand held assembly is attached to the electronics by a 10–foot cable. Each electronic drive is housed in an assembly that mounts in a standard 19–inch rack.

### 4.5 Mechanics

The CRT and optics retaining assemblies as well as the helmet attachment hardware, were tooled from 6061–T6 aluminum and anodized black. This material was selected for its strength, light weight as well as its ease of machinability. Two cylindrical tubes machined from solid stock are used to support and protect the CRTs as well as align the CRTs with respect to the optics assembly. The optics are secured to the cylindrical tubes via a customized optics bracket. Both CRT/optics assemblies are mounted on a bracket with a machined surface that allows for interpupillary adjustments as well as the capability for simultaneous vertical adjustment of both optical assemblies. Fore and aft adjustments for eyeglass relief are supplied via parallel rods on both sides of the helmet. These rods adjust the entire CRT/optics mounting plate so that parallelism between the two optics paths is always maintained.

## 5. DEMONSTRATION

Due to the design the CRT helmet system is a Forward, Image-Rastered, See-Through (FIRST), helmet-mounted display system. The FIRST helmet system has been demonstrated at Williams AFB by the Armstrong Laboratory as an OTW unlimited field of regard visual display system useful on part-task trainers. The helmet has also been demonstrated as a candidate for NVG training functions. The Combat Engagement Trainer (CET) and FIRST helmet system have been demonstrated at Brooks AFB in a long-haul network configuration with another part-task trainer to show the utility of the helmet-mounted display system for squadron level use. The helmet has also been demonstrated at the 1991 Interservice/Industry Training Systems Conference at Orlando, Fl. with the high fidelity F–16C Multi-Task Trainer.

## 6. CONCLUSIONS

The present helmet design, through demonstrations and system measurements, has provided positive data as a research device. All of the goals established at the beginning of the project were reached. The system is a low-cost monochrome CRT display that has been integrated to three different image generation systems. The optics are see-through for "in-cockpit" viewing and uses a head-tracking system for an unlimited field of regard. The system has also been integrated into a simulated NVG environment for initial demonstrations of its training potential for that task. The next step for enhancement of the helmet system is to evaluate peripheral cueing capabilities that can be incorporated into the device. To accomplish this, development of light-weight lens and mounting systems will need to be incorporated to reduce the overall weight of the helmet.

## 7. ACKNOWLEDGMENTS

Development of the Low Cost Monochrome Helmet-Mounted Display was sponsored by the Air Force Human Resources Laboratory, Human Systems Division (AFSC), United States Air Force, Brooks AFB Texas 78235–5601.

## 8. REFERENCES

1. MIL–STD–1472C, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, pp. 136–138, 2 May 1981.

Figure 1

Low-cost color LCD helmet display

Roger W. Leinenwever

GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

Leonard G. Best

GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

Bryce J. Ericksen

Consultant to GE Government Services,
WAFB Site Project Williams AFB, Arizona 85240–6457

## ABSTRACT

The goal of this helmet-mounted display (HMD) project was development and demonstration of a low-cost color display incorporating see-through optics. A full field-of-regard visual presentation was to be provided through the use of a head-tracker system and the HMD was to be suitable for use with low-cost cockpit trainers. The color imaging devices selected for the project are commercially available liquid crystal display (LCD) panels. The LCDs are 3.0 inch (diagonal) thin film transistor (TFT) types using a delta format for the red, green, blue (RGB) matrix. Fiber optic light panels mounted behind the LCDs provide a cool light source of greater than 3400 foot-lamberts (ft-L). Approximately 3 percent of the applied light source is emitted by the LCD image source. The video displayed is in a 3:4 format representing a 30° vertical by 40° horizontal biocular instantaneous field-of-view (IFOV) visual image from a graphic image generation system and is controlled in a full field of regard based on positional information from a head-tracker system. The optical elements of the HMD are designed as an exit pupil forming, see-through system and require the eye to be in a 15 mm volume for viewing the scene. The beam splitting function of the optics allows the user to see through the optics for reading cockpit instrumentation, while viewing outside the cockpit reveals the out-the-window (OTW) scene. The optic design allows for the IFOV to be displayed through a set of field lens, relay lens, folding mirror, beam splitter and spherical mirror system. The beam splitters and spherical mirrors for both optical paths are coated for approximately 50 percent transmission and reflectance. This approach, combined with the losses through the rest of the optical path, provides a theoretical maximum of 10.9 percent of the LCD image source intensity arriving at the eye. Initial tests of image intensity at the eye for a full white scene have measured at approximately 11 ft-L.

## 1. BACKGROUND

Over the past several decades, tremendous strides have been made in computer image generation for use with Department of Defense simulation devices. At the forefront of this simulation is the need to provide aircrew personnel the maximum amount of OTW visual information for flying various types of mission-related tasks. With the increase in technology in image generation came the need to display the images everywhere the aircrew member needed to look. At the same time, fighter aircraft designs were changing to provide crews even greater visibility from the cockpit. This, in turn, increased the requirement for image generators with greater capability and flexibility to support larger display systems. What started out as a one-window CRT visual display has blossomed into decahedron-based infinity optic CRT displays and full-field-of-view (FFOV) projection display dome systems. Although these high-fidelity systems provide capabilities to perform an extensive range of training functions, there are also requirements to accomplish effective training by utilizing low-cost visual display systems integrated with low-cost cockpit trainers. Simulators of this configuration do not demand as much facility space as required by large systems. This situation is a driving force for research in low-cost display devices that will meet requirements of Air Force mission task training.

## 2. INTRODUCTION

One of the areas of interest being researched by the USAF Armstrong Laboratory, Aircrew Training Research Division (formerly The Air Force Human Resources Laboratory, Operations Training Division) is low-cost display systems utilized in training Air

Force crews on simulators and part-task trainers. One type of display system being investigated is the helmet-mounted display (HMD). A prototype HMD system which utilizes liquid crystal display technology was designed, manufactured, assembled and demonstrated for Armstrong Laboratory under contract F33615-88-C-0014 with GE Government Services at Williams AFB, Arizona.

## 3. SYSTEM DESIGN

The project goal for the LCD-based HMD required a see-through, color system which would be suitable for low-cost cockpit trainers. The HMD would be compatible with the use of a headtracker to allow a full field of regard, providing more flexibility in training capabilities than a forward fixed visual scene. Considerations in the HMD system design are presented in the paper as follows: the image display system, the optical system, and mechanics.

### 3.1 Image display system

The image display consists of the LCD panel, the electronics to drive the LCDs, and an illumination source. The LCD image source for the HMD utilizes Sharp Corporation 3.0 inch (diagonal) Thin Film Transistor types using a delta format for the RGB matrix. TFTs in many LCD panels are juxtaposed such that each element is collinear with adjacent elements in both the horizontal and vertical directions. The delta format employed in the Sharp panels differs from this collinear positioning by placing the TFTs in a triad configuration, each triad containing a red, green and blue constituent. The triads are closely packed together to produce horizontal lines. Each alternating line of triads is slightly offset horizontally so that no single triad is positioned directly in line vertically with an adjacent triad. This configuration serves to minimize the visual effects of the linear patterns which are evident in the more commonly configured LCD panels. Due to an alternating number of triads in each line, the average horizontal resolution is 382.5 elements, while the vertical resolution is 234 lines, providing a total of 89,505 triads in the Sharp LCD panel matrix.

The electronics, integral to the LCD housing, require four externally regulated, low voltage DC power sources, as well as RS170A (15.75 KHz horizontal scan rate) RGB video with a separate sync as inputs. The power sources for each LCD are sequenced up and down in a specified order during power on and off functions via an EPROM-controlled microprocessor system. The microprocessor also monitors the power sources during operation and will phase the system down if it detects a supply slipping beyond an established limit. The LCDs can be damaged if all the supplies and video are not controlled properly. The sequencer and video control circuits are designed to accommodate the unique video and contrast functions of the Sharp LCD units. Complex video reversal at alternate horizontal line rates combined with pulsed DC amplitude control on variable DC levels have dramatic effects on video brightness, contrast and off-angle viewing of the LCDs. Direct viewing (zero degree angle of incidence) requires near maximum settings for most of the controls.

In order to view the LCD imagery, a source of diffused light must be applied directly behind the LCD panel. A maximum of 3 percent of the applied source is emitted by the LCD image source. Because the LCDs can become damaged by excessive heat, a potential problem exists in attaching a lamp in close proximity to the LCDs with sufficient brightness for this particular HMD application. This problem is eliminated by projecting a 150W halogen lamp with adjustable intensity into a flexible nylon fiber optic bundle 7 feet in length. The fiber optic bundle, manufactured by Lumitex, Inc., is split at one end, providing light for both LCDs. The strands of fibers at the split bundle ends are interwoven into rectangular panels one-eighth inch thick, and are sized to overlay the dimensions of the LCD format. The woven back-light panels are covered with translucent mylar to package each panel, as well as increase light diffusion. By remotely locating the lamp from the LCDs in this manner, only the light is transmitted to the LCD area, while the heat remains near the lamp source. The light output for each fiber optic panel exceeds 3400 ft-L and has a color temperature of approximately 2850° K. The brightness fall-off toward panel edges is within 10 percent. The difference in luminance levels between the two panels is below 6 percent.

### 3.2 Optical System

The optical system design efforts were performed in coordination with Martin Shenker Optical Design, Inc. The optic elements of the LCD helmet are designed as a see-through exit pupil forming system and require the eye to be within a 15 mm volume for viewing the scene. This arrangement requires the wearer of the helmet to be at a critical location with respect to the eyepiece to be able to view the scene presented by the optics.

In order to provide a balanced helmet system, the design places the LCDs aft of the helmet center. This rearward placement extends the length of the optical path, requiring that a relay lens system be placed in the optics chain in order to deliver the imagery to the eye.

The optical components necessary to provide the LCD imagery with proper magnification and focus to both eyes are listed as follows: a field lens placed near the LCD image plane; a relay lens system containing two doublets and three single elements placed forward of the helmet center; a first surface mirror folding the path 90° horizontally inward; and the eyepiece, containing a thin plate beam splitter which folds the ima[illegible]0° horizontally forward, and a doublet with a spherical mirror surface, which outputs the imagery back to the eye in the fin[illegible] by 40° H FOV format. Glass types used in the system include BK7, SF156, K5, BAK2, LAF21, and FK5. The thin plate beam splitter is chemically tempered to help prevent shattering.

Due to the see-through capability of the system, the optical surfaces are coated to provide a maximum of 10.9 percent of the applied LCD image source to the eye, while 24.8 percent of the outside environment is transmitted through the eyepiece for viewing of cockpit instrumentation. Proper focus of the display is maintained by accurately controlling the position of the LCD image surface with respect to the field lens location. Brightness of the display through the optics chain for white scene content on a dark background has been measured at approximately 11 ft-L, with a contrast ratio of greater than 85:1.

Since a single source of video is applied to both LCDs, the imagery to the eyes is completely overlapped, thus providing a biocular display. The three-inch format of the LCD requires approximately 2.3 times magnification by the optical system in order to obtain the proper 30° V by 40° H FOV. Resolution for this FOV specification provides 6.28 arc minutes per LCD triad horizontally, while the vertical resolution is 7.69 arc minutes per triad.

### 3.3 Mechanics

The mechanical arrangement of the color LCD HMD produces a well-balanced system. The optics and LCDs are attached to an extra large helmet of standard AF issue. Since this HMD is of prototype design, an air bladder system (designed for use with football helmets) is used as a liner for the helmet and contains inflation points for two separate sleeves. The bladders are pressurized as required to provide a secure fit of the HMD to the user so that the imagery remains within the eyepoint as head motion is performed.

The optics are designed so sufficient mechanical clearances are available at the sides of the helmet to accommodate the optical fold configuration. The optic chains have a 10° outward offset in the aft direction with respect to the line of sight. Each optic chain can be mechanically adjusted for proper interpupillary distance (IPD), fore/aft, and vertical positioning to provide fitting of the optics/helmet arrangement to military aviators in the 5th to 95th percentile range[1]. However, the angle at which the flat beam splitter is positioned with respect to the face of the user precludes the use of eyeglasses with the HMD system.

The optic elements are housed in lens cells manufactured primarily from 2024–T3 or 6061–T6 aluminum. These materials were selected because of their high strength-to-weight ratio and ease of machinability. The center-of-gravity for the HMD is very close to the geometric center of the helmet, and the overall weight is approximately 7 1/2 lbs., including a portion of the weight added by the cables for the LCDs and back-light panels.

## 4. DEMONSTRATION

The low-cost, color, LCD helmet-mounted display system has been demonstrated at Williams AFB by the Armstrong Laboratory as an OTW unlimited field-of-regard visual display system for use on low-cost part-task trainers. The system was also shown as a technology demonstration for helmet-mounted, color visual, see-through displays at the Interservice/Industry Training Systems Conference (I/ITSC) in Orlando, FL., in December 1991. The system is scheduled for use in a virtual reality study to be conducted by Armstrong Laboratory research psychologists at Williams AFB.

## 5. CONCLUSION

The goal for this project, to produce a prototype configuration low-cost, color, helmet-mounted display system with see-through capabilities, was successfully completed at the USAF Armstrong Laboratory at Williams AFB, AZ. Although the resolution of the LCD matrix structure is not suited for the application of small text in the presentation, the high contrast and vivid colors produced by the LCD, as well as the see-through function of the optics, provides the capability for a full field-of-regard visual simulation system which can be used in conjunction with low-cost cockpit training devices. As color LCD manufacturing techniques improve and higher resolution panels become available, the applications for simulation and training with the LCD HMD will expand. The versatility and complexity of this visual training will provide wide field-of-view peripheral cueing, or capabilities for training in the acquisition of small, high resolution targets.

## 6. ACKNOWLEDGMENTS

Development of the Low-cost Color LCD Helmet-Mounted Display was sponsored by the Air Force Human Resources Laborat Human Systems Division (AFSC), United States Air Force, Brooks AFB Texas 78235-5601.

## 7. REFERENCES

1. MIL-STD-1472C, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, pp. 136-138, 2 M 1981.

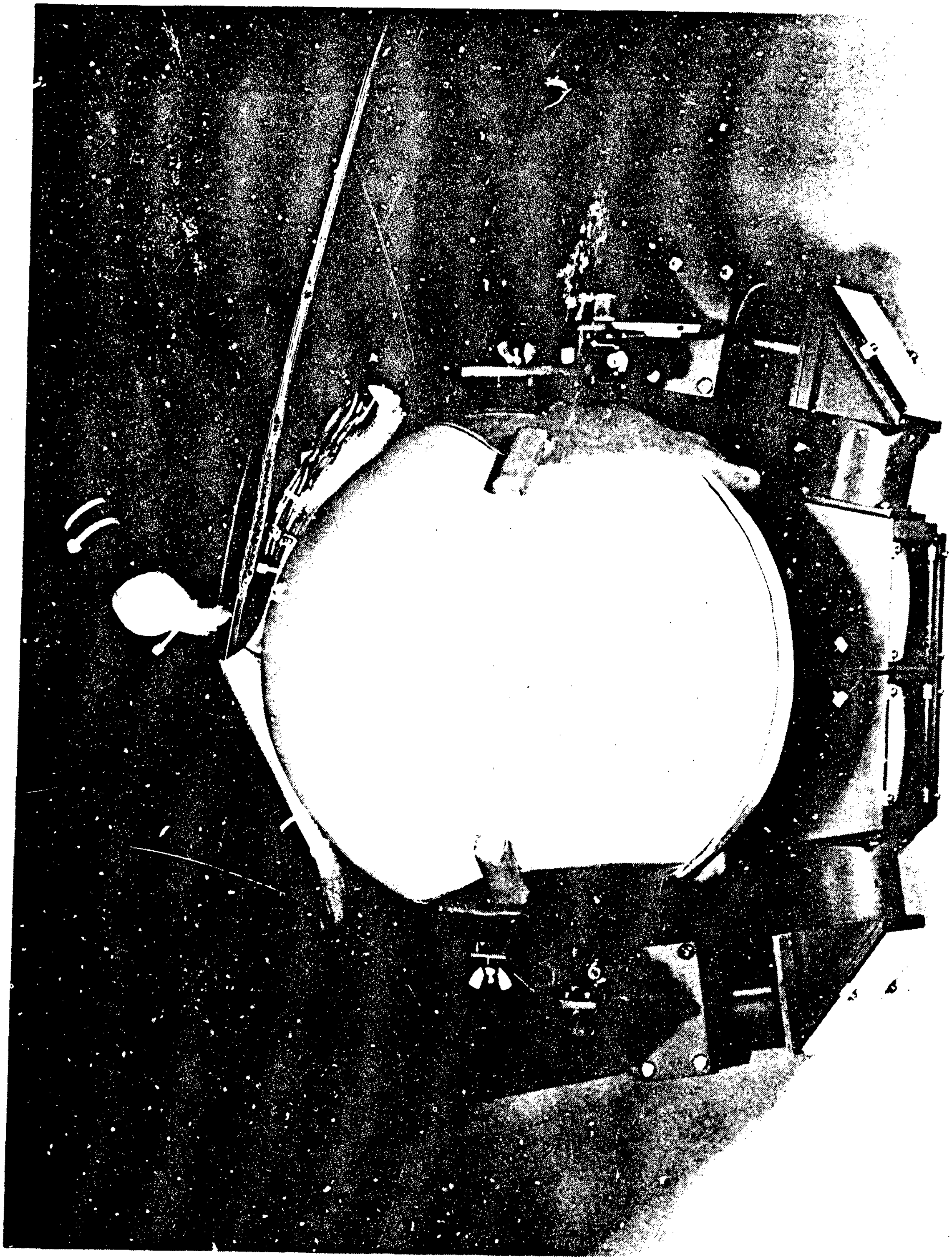

Figure 2
Low-cost Color LCD Helmet Display